Article:

Roberts, M., Byg, A., Faccioli, M. et al. (2 more authors) (2021) Stakeholder perceptions of public good provision from agriculture and implications for governance mechanism design. Journal of Environmental Planning and Management, 64 (2). pp. 289-307. ISSN 0964-0568

https://doi.org/10.1080/09640568.2020.1763274

Journal of Environmental Planning and Management
Routledge
Taylor & Francis Group

Stakeholder perceptions of public good provision from agriculture and implications for governance mechanism design

Journal:	*Journal of Environmental Planning and Management*
Manuscript ID	CJEP-2019-0307.R2
Manuscript Type:	Research Article
Keywords:	agriculture, Public goods, Fuzzy Cognitive Mappting, Goverance, Land Management
Abstract:	Agriculture provides many public goods; however the costs and benefits of these are rarely well distributed. Maintaining public good provision often relies on external governance mechanisms, in turn reliant on the existing socio-ecological system. With two groups of stakeholders (practitioners and academics) we created cognitive maps of socio-ecological systems linking agriculture, public goods, and governance mechanisms in north-east Scotland. Fuzzy cognitive mapping was used to explore stakeholders' perceptions and experiences, and to assess alternative governance options for the local socio-ecological context. We find agreement for perceptions of the system between stakeholders, but differences in each group's focus. Models predicted little change in the provision of public goods from agriculture in relation to different governance mechanisms. We find that stakeholder participation can aid understanding of the impacts of proposed governance changes at the local level, improving comprehension of stakeholder perception of impacts and understanding of stakeholders' reactions to particular governance mechanisms.

Stakeholder perceptions of public good provision from agriculture and implications for governance mechanism design

Abstract

Agriculture provides many public goods; however the costs and benefits of these are rarely well distributed. Maintaining public good provision often relies on external governance mechanisms, in turn reliant on the existing socio-ecological system. With two groups of stakeholders (practitioners and academics) we created cognitive maps of socio-ecological systems linking agriculture, public goods, and governance mechanisms in north-east Scotland. Fuzzy cognitive mapping was used to explore stakeholders' perceptions and experiences, and to assess alternative governance options for the local socio-ecological context. We find agreement for perceptions of the system between stakeholders, but differences in each group's focus. Models predicted little change in the provision of public goods from agriculture in relation to different governance mechanisms. We find that stakeholder participation can aid understanding of the impacts of proposed governance changes at the local level, improving comprehension of stakeholder perception of impacts and understanding of stakeholders' reactions to particular governance mechanisms.

Keywords: Agriculture, Public Goods, Fuzzy Cognitive Mapping, Governance, Land Management

1 Introduction

Agricultural systems are well recognised for the provision of ecosystem services (Cooper, Hart, & Baldock, 2009; Hunter, Guarino, Spillane, & McKeown, 2017; Potschin, Haines-Young, Fish, & Turner, 2016; Swinton, Lupi, Robertson, & Hamilton, 2007), defined as benefits humans derive from environmental systems (Millenium Ecosystem Assessment, 2005). Although some of these services, such as food production, are market goods which can be traded, many, such as views of agricultural landscape, recreation or biodiversity, are 'public goods'. Public goods include all goods which are, in varying degrees, non-excludable (no person can be prevented from using the service) and non-rivalrous (use of the service by one individual does not reduce the availability to others). Public goods are not limited to ecosystem services, and include goods such as education, and not all ecosystem services act as public goods (e.g. sale of fishing licences). Public goods fall outside of traditional markets, and promoting public goods on agricultural land can incur private cost to landowners and managers (Westhoek, Overmars, & van Zeijts, 2013). Policy and governance mechanisms, (e.g. regulations, green labelling) may therefore be needed to incentivise public good production (Westhoek et al., 2013). An overview of ecosystem services, both as market and public goods, can be found in Swinton et al. 2007.

Agricultural land is therefore the site of many competing interests, involving both public and private goods such as increasing crop yield, reducing soil run-off, and maintaining public access. Management is therefore characterised by uncertainty and often does not conform to traditional assumptions about the existence of a single optimal solution (Duckett, Feliciano, Martin-Ortega, & Munoz-Rojas, 2016). Additionally the connections between agricultural, ecological and social systems are often data-poor and context-specific. Under these circumstances stakeholders themselves can therefore hold valuable knowledge which may reduce uncertainty and increase data availability (Voinov & Bousquet, 2010).

Stakeholders have a unique understanding about the systems they work and live in, and how governance mechanisms interact with these systems (Voinov & Bousquet, 2010), for example how timing of forage cutting may alter cattle stocking rate (Vanwindekens, Stilmant, & Baret, 2013), or the impact of bureaucracy on uptake of management (Christen, Kjeldsen, Dalgaard, & Martin-Ortega, 2015). The inclusion of a diverse range of stakeholders can therefore improve policy mechanism design. This involvement should take account of the heterogenous nature of stakeholders, recognising that they do not all hold the same views, beliefs or motivations or operate under the same socioeconomic realities and face the same barriers and opportunities. Accounting for a diversity of actors (e.g. farmers, researchers and policy makers), perspectives (e.g. organic and conventional farmers) and institutions (e.g. governmental, non-governmental and community groups) improves the ability of policy to engage with broad issues, identify novel approaches and increases support and reduces resistance to new or changed governance mechanisms (Anggraeni, Gupta, & Verrest, 2019; Baird et al., 2019; Doukas & Nikas, 2019; Reed, 2008). Stakeholder knowledges of agricultural systems are based not just in individually held ideas, but also in relation to the network of connections they make to other actors and biotic and abiotic elements of the system. Stakeholders and stakeholder knowledges therefore influences final behaviours, tied to the context of the agricultural, ecological and social systems (Allen, Quinn, English, & Quinn, 2018; Bremer et al., 2018; Thompson, Reimer, & Prokopy, 2015). Accordingly, inclusion of stakeholders in development of governance mechanisms can improve their chances of success, although it is important to note that this will only be effective where this insight is carried through to policy design and implementation, and is experienced as more than a 'tick-box exercise' (Anggraeni et al., 2019; Reed, 2008). Capturing stakeholder insight is particularly timely for EU agricultural policy post 2020, when member states will have higher flexibility in administering the Common Agricultural Policy (CAP, European Commision, 2018), and for the UK following Brexit (e.g. Health and Harmony consultation on Green Agriculture after Brexit (Department for Environment Food and Rural Affairs, 2018).

The success of governance mechanisms in promoting public good provision depends not just on the design of the promoted interventions (e.g. how and when do hedgerows benefit biodiversity) but also their implementation (e.g. how hedgerows are planted following PES scheme) and uptake (e.g. how many hedgerows are planted following PES scheme) (Figure One). Uptake is influenced by stakeholders' perceptions of the mechanisms, the perceptions of the mechanisms within the community, individual socioeconomic realities and fit with existing practices, as well as the ways in which the mechanisms interact with the socio-ecological system, and how stakeholders evaluate these interactions and potential outcomes (Allen et al., 2018; Bremer et al., 2018; Morris, Mills, & Crawford, 2000; Thompson et al., 2015). Taken together, this influences the acceptability and success of particular mechanisms and hence their direct impacts on public goods, because uptake of mechanisms, however theoretically impactful, will be low if this impact is not perceived.

[Figure One here]

Mental modelling provides one method for facilitating stakeholder participation (Doukas & Nikas, 2019; Fairweather & Hunt, 2011). Mental models involve the creation of diagrammatic representation of a system, identifying concepts, and the links between them, to explore how changes are perceived to move through the system. This creates a more formal representation of stakeholders' own conceptual models of how a system works (Voinov & Bousquet, 2010). Fuzzy cognitive mapping (FCM) is one form of semi-quantitative mental modelling (Özesmi & Özesmi, 2004). FCM expands the cognitive mapping method to include scoring of the strength connections between attributes of the system (Kok, 2009; Özesmi & Özesmi, 2004;

Papageorgiou & Kontogianni, 2012). FCM provides a useful tool to link storylines to models, and is generally well received by participants (Vliet, Kok, & Veldkamp, 2010). Because FCM captures perceptions of the system, rather than empirical data (although this can be added to models), they do not necessarily produce a single 'true' model, but one which represents the expectations of the stakeholders. Involvement of a broad, well targeted, range of stakeholders is therefore important (Anggraeni et al., 2019; Baird et al., 2019; Christen et al., 2015; Doukas & Nikas, 2019). The participatory aspect of FCM also brings limitations, most obviously the potential to code incorrect data, that data collected is limited by the stakeholders involved, and context surrounding the links may be lost (Gray et al., 2015; Kok, 2009; Özesmi & Özesmi, 2004). FCM can also be used as part of a larger research or policy design exercise, which may incorporate more traditional methods of data collection, such as surveys of users or ecological surveys. We do not explore the models underlying FCM in this paper, nor do we contribute to FCM theory and modelling, as this has been carried out extensively elsewhere (e.g. Özesmi and Özesmi (2004), Papageorgiou and Kontongianni (2012), and reviewed by Doukas and Nikas (2019)).

FCM is of particular use in environmental and agricultural systems because it is able to create a tangible representation of stakeholder perceptions, including not only direction of links, but their strength, increasing knowledge of, and reducing uncertainty surrounding, these often data-poor systems. FCM can prove particularly valuable for increasing the visibility of assumptions made by stakeholder groups, increasing opportunities for these to be scrutinised, identifying areas where contention or a lack of consensus may cause difficulties, and highlighting where options for intervention may be available. Because a visual map is created, stakeholders can present elements of the system which may not be apparent through a direct interview, because they are thought to be self-evident (Vliet et al., 2010). Because FCM is able to utilise natural language to formalise outcomes of discussion and exploration of a system by stakeholders there is the opportunity not just for stakeholders to contribute their knowledge, but to view and adjust the resulting models, and use these model to explore uncertainties within the system (Kok, 2009; Özesmi & Özesmi, 2004; Vliet et al., 2010). This can be particularly valuable for highlighting the stewardship values associated with managing agricultural systems, which have been linked to increased environmental action (Allen et al., 2018; Thompson et al., 2015). With regards to public goods stakeholder participation through FCM has been used to understand breaches of regulations regarding bank erosion and diffuse pollution (Christen et al., 2015).

Through FCM, this study seeks to understand how distinct stakeholder groups perceive public good provision from agriculture, and how these groups perceive the impacts of governance or policy changes. We use the case study of the Ugie river catchment, Aberdeenshire, Scotland (UK), which was identified with stakeholders as an area of high priority for public good provision, in particular for biodiversity and water quality.

2 Materials and Methods

2.1 Study area and wider project

The river Ugie is located in North East Aberdeenshire (Figure Two). The catchment is dominated by mixed farming, predominantly of beef and cereal, with potatoes, oilseed rape, pigs, sheep and poultry also produced. Mean farm size is 47ha (Aberdeenshire Council, 2017). The Ugie is a source of drinking water and one of the Scottish Environmental Protection Agency's diffuse pollution priority catchments due to failing to meet environmental standards (SEPA, 2015). Previous research (as part of PROVIDE H2020, for full explanation of project see Appendix A) with stakeholders in Aberdeenshire (e.g. representatives from environmental organisations and the forestry sector) has identified this area as of high priority for public goods, in particular water quality and biodiversity (Creaney, Novo, Byg, & Faccioli, 2017). Stakeholders previously identified appropriate governance and policy to improve provision of these goods, including different forms of subsidies, taxes, regulation, cooperative approaches, awareness, public opinion and market mechanisms. These mechanisms were identified as important either due to their large impacts on farm viability (e.g. subsidies), successful trials carried out elsewhere (e.g. catchment partnerships), or potential for changing the mechanism in the future (e.g. likely shift in agricultural policy in the UK post-Brexit). The mechanisms identified form the basis of the fuzzy cognitive mapping exercise. For full explanation see: Byg, Novo, Faccioli, & Kyle, 2017.

[Figure Two here]

2.2 *Fuzzy Cognitive Mapping*

FCM is a semi-quantitative, typically participatory, conceptual mapping approach. FCM is made up of 'Concepts' representing elements of a system (e.g. crop yield) which are joined by single direction links, although concepts may be linked by two links in opposing directions (e.g. yield have small positive impact on amount of crop planted, and amount of crop planted a large positive impact on yield), the underlying assumptions for multiple links must be carefully considered in the context of the system. Links can be positive (increase in one concept leads to an increase in the second) or negative (increase in one concept leads to a decrease in the second) and are assigned a score for their strength compared to other links in the system (Kok, 2009; Özesmi & Özesmi, 2003, 2004). Because these are relative scores they cannot be used to estimate absolute magnitude of impact (Papageorgiou & Kontogianni, 2012). FCM may involve individuals or groups, and maps can be combined to create a consensus map.

Maps can be described in terms of the number and types of links they contain, known as matrix indices, providing information on the structure of the system as perceived by stakeholders. The number of links, concepts, and connection density (i.e. the number of connections per concept) indicates the relatedness of concepts within the system as perceived by the stakeholders involved in the FCM. This is important when altering the system, such as through policy change, as a more interlinked system has larger potential for side effects (Özesmi & Özesmi, 2004), although the diversity of stakeholders involved in the FCM must also be considered, with more complexity often seen with more diverse stakeholder involvement (Baird et al., 2019).

Models are created from these maps using the scores given to links between concepts. This process is typically first carried out using stakeholder assigned values, representing the baseline or calibrated model. To understand how changes to model concepts can influence other concepts, the models can be simulated by changing the concept values, indicating an increase or decrease in the importance of the concepts. Comparing equilibrium scores between the 'no changes' and the 'changes' models estimates how concept changes may impact throughout the system. Jetter and Kok (2014) provide an accessible overview of FCM in practise, and for a full explanation of FCM models see Özesmi and Özesmi 2003 and 2004.

2.3 Stakeholders

Stakeholders included academics researching Scottish agriculture (based at the James Hutton Institute) and land managers (practitioners e.g. farmers, fishery managers, land agents) working in the Ugie river catchment. Academic stakeholders were selected for their knowledge of wider agricultural systems and governance mechanisms and included natural and social scientists. Practitioners provided in-depth knowledge of the context of agriculture along the Ugie. Inclusion of practitioners was of particular importance as they are often excluded from such consultations. Within the wider project (PROVIDE, see Appendix A) policy-makers and a wider array of stakeholders (e.g. representatives from environmental organisations and the forestry sector) have also been consulted through four workshops, including identification of potential governance mechanisms for public good provision which have been used in this FCM exercise, and later evaluation of the results of the FCM models. However, policy makers were not consulted directly to create FCMs, due in part to funding and time limitations, and understanding that policy maker voices are heard by default in design of state-led governance mechanisms (Takacs, 2019). The work presented here therefore sought to identify the data normally missing from such discussions. Separate workshops were held for academics and practitioners, with 11 and 8 participants respectively. While mixed workshops are good for promoting dialogue and creating a shared understanding of a system amongst different stakeholders we chose to hold separate workshops to enable clearer identification of the differences in perceptions held by distinct stakeholder groups.

2.4 Workshop design

Workshops began by introducing participants to the case study and public goods. To facilitate map creation we used the Mental Modeller interface (Gray & Cox, 2013). This provided a canvas onto which concepts and links could be drawn and results directly exported. The interface enabled simple models to be created, allowing stakeholders to view, validate and modify the outcomes of their mapping.

Participants were split into groups to consider either biodiversity or water quality. In order to decrease the cognitive burden on the participants they were presented with maps already containing key concepts identified through previous stakeholder workshops (Byg et al., 2017; Creaney et al., 2017), but were told that they could add or delete concepts to create a model that matched their understanding of the system (Table One). Participants discussed the presented concepts and altered concepts according to perceptions. Discussions included the definition of each concept that would later be used to match concepts between maps. This ensured that we were able to match concepts in terms of the definitions used by stakeholders (i.e. concepts which had the same definition but different names by stakeholders could be compared due to the explicit discussion of definition), which may have differed to prescribed definitions. Some concepts were later merged (e.g. elements of biodiversity) to enable comparison and prevent double counting of impacts. Participants added links between concepts to illustrate how they understand the system to function. Links were restricted to between -1 (strong negative) and +1 (strong positive) but were not otherwise limited. Links and concepts were added, edited or removed by the facilitator once a consensus had been reached among the participants.

[Table one here]

After maps were created models were run making no changes to scores assigned by stakeholders. Models were then re-run setting the scores for the links between policy and governance and the public goods artificially high, for stakeholders to compare model outputs. Stakeholders were able to view the outcomes of their maps and identify where mistakes may have been made, or relationships needed to be adjusted (i.e. where changes to one concept produced illogical changes in another concept). Giving the option to feedback on results is important to fully understand stakeholder knowledges and providing stakeholders with further ownership over the final models. Both will improve the quality of the model outcomes and applicability.

2.5 Scenario development

Scenarios development did not involve direct stakeholder input, but were used to further explore implications of the models after the workshops had been conducted. Scenarios were developed from the maps to include those governance mechanisms which were most closely linked to either water quality or biodiversity, because these were the focus of our study. We identified concepts directly linked to either water quality or biodiversity, and those concepts indirectly linked to water quality or biodiversity (i.e. connected through one intermediate link) (e.g. public pressure impacts green agriculture, which in turn impacts water quality). Due to the form of the model (i.e. dilution of impacts where concepts are linked more distantly) these concepts were most likely to have the largest impacts on public goods, and therefore are the concepts best targeted for change in governance mechanisms. Concepts were then thematically grouped to represent consistent governance changes. Concepts separated by more than two links (i.e. with more than one intermediate step connecting them to water quality or biodiversity) were not altered in scenarios because they are expected to have smaller impact on public goods, and always through an intermediate concept which was included within the scenarios. These concepts remain in the model as a whole. All mechanisms chosen for alteration within the scenarios were initially identified as important in either the workshops presented here, or previous workshops (Byg et al., 2017). Scenarios are described in the results section. The percentage change in equilibrium values (i.e. the final values of each concept after the model has been run) between the modelled and no changes scenario were compared. These are relative values and are therefore grouped into high, medium or low change, to prevent false comparison.

2.6 Quantitative analysis

Quantitative analysis did not involve further stakeholder engagement.

The maps created by stakeholders were exported from the Mental Modeler interface. All analysis was carried out in R using the FCMapper (V1.1) package (Turney & Bachhofer, 2016).

Matrix indices provide a means to quantitatively compare map structures. Matrix indices were calculated (function: matrix.indices) for the academic and practitioner maps for water quality and biodiversity. Because each group had the opportunity to alter concepts, the maps created by academics and practitioners for each public good varied and concepts considered were compared. For full details of calculation of matrix indices we refer readers to Özesmi and Özesmi (2004).

To enable comparisons between models, concepts that had been split (e.g. biodiversity in the academic water quality map) were recombined, and the mean value was used (Papageorgiou & Kontogianni, 2012). Although stakeholders had been able to set links to any value between 0 and 1, discussion surrounding the links referred instead to qualitative levels (e.g. low, medium and high). To reflect this we therefore rounded each value to the nearest quarter, reducing the potential for false accuracy.

Models were initially simulated with no fixed concepts (i.e. the values given by the stakeholders, function: nochanges.scenario) to estimate equilibrium values (i.e. the values of each concept once the model becomes stable, concept values do not fluctuate with additional iterations) for the current system. Transformation was by the logistic function, and simulations were run for 20 iterations and considered converged if $i19=i20$. This was then repeated for each governance mechanism scenario with selected concepts fixed to 1 (function: changes.scenario). Scenario development is described in the preceding section. The equilibrium values of the no changes and changed models were compared (function: comp.scenarios).

Finally academic and practitioner models were combined. To estimate the link between each concept the mean value was taken for those links where a non-zero value was present in both models. For example, if the link between public pressure and green agriculture was 0.2 in the academic model and 0.4 in the practitioner model the combined model would estimate this link as 0.3. If concepts were only related in a single model then in the combined model the link was equal to the value given in the model in which the link was present (e.g. agri-environment schemes link to green agriculture was considered only in the practitioner model for biodiversity and not in the academic model). This method of combining was selected as the common links between models were largely similar but differing expertise of academics and practitioners led them to identify different links from one another. The selection of this method of combining, rather than assuming missing links represented zero links and calculating the mean in all cases, was supported by the discussions with stakeholders while creating the models, in that no stakeholders explicitly stated zero for any link, but rather expressed uncertainty.

3 Results

3.1 Building maps

In all groups, creating conceptual maps led to lively discussions about not only linkages between different concepts, but also the meanings of the concepts themselves. Some of these discussions were reflected in the final models through renaming, splitting, deleting or adding concepts, while other aspects were captured in the recorded discussions and the researchers' notes. An example of an FCM can be seen in Figure Three, for all others see Appendices B:D.

[Figure Three here]

3.1.1 Biodiversity

Despite providing pre-populated maps drawing on previous stakeholder workshops, there are differences between academic and practitioner maps in terms of concepts considered when conceptualising the public goods related to agriculture (Table One). The practitioner map focused on concepts with direct impacts on agriculture (e.g. splitting 'Agricultural supply chain' into input and output supply chain), while the academic map placed emphasis on different types of biodiversity and green agriculture (e.g. splitting 'Biodiversity' into farmland birds, soil fauna, pest species, aquatic species, arable weeds, and pollinators). Structures of both maps are similar.

3.1.2 Water quality

The differences between academic and practitioner maps for water quality are fewer than those in the biodiversity maps. Practitioners split regulations and subsidies into more specific measures, while the academics added green subsidies and retail pressure (Table One). The practitioner map contained one more concept than the academic map. Both maps have similar structures.

3.2 Combined fuzzy cognitive maps from academics and practitioners

3.2.1 Biodiversity

The combined model contains all links present in each individual model, and therefore contains a higher number of connections per variables than either model individually. As a result changes to concepts may be higher in the combined model than either individual model. The number of links present in the combined biodiversity model was 64, across 30 concepts.

Equilibrium values for the no-changes scenario indicates the baseline level of each concept, to which scenarios can be compared. Differences between models above 0.2 (as recognised a large compared to other concepts) are seen for: farm viability, biodiversity, water quality, agricultural yield, water flow and water security (for full results see appendix F).

Links between concepts which appeared in both the academic and practitioner models agreed with regards to the direction (i.e. they were either both positive or both negative). This indicates there was agreement in the type of interaction between concepts, though the perception of strength may differ. For all links that appeared in both models the mean link value was taken for the combined model. Where a link appeared in only one model this value was used in the combined model. Although taking the mean values of links has the potential to create a model which represents neither view well and neutralises differences across stakeholders (Özesmi &

Özesmi, 2004) this would be of limited impact in our case because no links were in direct opposition.

3.2.2 Water quality

The combined water model contains 43 connections across 23 concepts. Therefore equilibrium values in the combined model can exceed those on each individual map.

The link between green agriculture and agricultural yield took opposing values in the water quality maps, being negative in the academic map, and positive in the practitioner map. Because of this, taking the mean value for this link would not have represented either map accurately (i.e. the link would have been shown to be zero, where this is not true in either map). To avoid this we created three alternative combined models with the link between green agriculture and agricultural yield set to 0 or the level expected from the practitioner (0.63) or academic (-0.28) models. We ran these models and compared equilibrium values to understand the impact of the link between green agriculture and agricultural yield on other concepts. Because equilibrium values showed little difference between models we carried out all further analysis with this link set to 0. Because the link between green agriculture and agricultural yield was removed the combined model cannot be used to describe agricultural yield.

Comparisons of equilibrium values between the combined, academic and practitioner models showed only water flow with a difference of over 0.2.

3.3 Scenarios

To design governance change scenarios we identified those concepts with the highest influence on water quality or biodiversity to simulate situations in which governance mechanisms worked to their highest potential as opposed to the current perception. Because green agriculture had the largest direct impact, we also identified the concepts linked to green agriculture. Stakeholders were not involved in scenario design.

3.3.1 Biodiversity

The concepts with the highest, positive impact on green agriculture (as identified above as the strongest link) were grouped into three scenarios:

1. Improved policy: Agri-environment schemes and CAP increased
2. Changed agriculture: Promoting traditional crops and shortening the agricultural supply chain increased
3. Improved technology: Technological advances increased.

Biodiversity is predicted to improve to some extent in all scenario models, with highest changes in the improved technology scenario (Table Two). Full results can be seen in the Appendices H:J.

3.3.2 Water quality

The concepts with the largest predicted impacts on water quality via impacts on green agriculture were organised into three scenarios:

1. Improved policy: catchment partnerships, agricultural regulations and green subsidies increased.
2. Public and retail pressure: Public and retail pressure increased.
3. Increased education: Education increased.

Water quality increases were predicted for all models, with highest changes in the improved policy scenario (Table Two).

[Table Two here]

4 Discussion

4.1 Maps and Models

The maps created by academics and practitioners varied in the concepts and links considered, despite stakeholders beginning with maps pre-populated with the same concepts, which had been identified in previous workshops. Academic maps focused on biodiversity and green agriculture, while practitioner maps were more concerned with direct agricultural effects. This difference in focus of academic and practitioner maps relates to the differing expertise, and likely to the different values, held by both groups. Although practitioners involved in this process supported mechanisms to improve farm ecosystems, their primary concern, and therefore primary expertise, is on how changes will impact their outputs, and therefore their livelihoods. Although academics involved in the process understand that agricultural outputs must be maintained, their priority, and expertise, is environmental outcomes. The difference in concepts considered by varied groups of stakeholders highlights the importance of multiple stakeholder views and priorities in policy design, and particularly of including practitioners alongside academic 'experts' (Anggraeni et al., 2019; Baird et al., 2019; Bosma, Glenk, & Novo, 2017; Christen et al., 2015) in order to perceive links which may not be observable to a single group. While such differences can also be elicited and documented in other ways, FCM increases the visibility of assumptions held by different stakeholders through the creation of a literal visual representation of the perceptions of stakeholders, leading to connections being presented that may not be verbalised through interviews because they are believed to be self-evident. In the case of the Ugie river catchment through FCM we were able to recognise that stakeholders held different, but not opposing, assumptions. In policy making experience by practitioners is often excluded not by design, but through the mechanism by which evidence is gathered in responses to a wide, relatively unspecific, call (e.g. Department for Environment Food and Rural Affairs, 2018), or though implicitly favouring views of the proponents of change (often industry or governments) or research (Takacs, 2019). Our results using FCM indicate that this exclusion may lead to a restricted number of implications of policy change being considered, even where there is general agreement in the way in which the system functions.

The collaborative and discursive nature of stakeholder participation through FCM has advantages over traditional modelling, either from empirical data or existing literature, in allowing for increased understanding of concepts to different stakeholders, and improved confidence in the links between concepts. In our Ugie river case study practitioners noted that although they could make links between promotion of traditional crops and other concepts, the lack of markets and interest to take what was, to their mind, a step back in progress meant that the mechanism would not be adopted. This deeper understanding, which could only be captured through stakeholder participation, is of high importance to policy making and mechanism design, as well as a research tool. FCM is able to formalise the outcomes of the discussions and exploration around the mapping exercise, and create models of highly complex systems under imperfect data, incorporating knowledges, perceptions and beliefs from multiple stakeholders. Beyond only contributing their knowledge stakeholders can view the outcomes of their modelling, adjust models to best reflect their realities, and use the models to explore uncertainties within the system. On viewing the outcomes of the water quality model the academic group were able to better consider the consequences and rationale for links to water in particular. Although no changes were made as a result of this deliberation it provided a catalyst for considering more carefully the links created, and therefore increased certainty in the resulting model. Participation not just in providing data, but also in analysing the results, can increase ownership of the process for stakeholders, improving accuracy of data, and applicability for policy decisions.

The concepts perceived to impact biodiversity or water quality were similar in academic and practitioner maps. However, outgoing links were fewer in the practitioner maps than the academic maps. While academics recognised public goods as impacting yield and water quality (biodiversity model) and biodiversity and habitat (water quality model), practitioners perceived a link only from water quality to reduced health concerns. While this may be an artefact of the task focus on the production of public goods, this may also indicate that practitioners do not perceive wider benefits of public goods, while academics may be biased towards perceiving larger benefits due to the focus of their work. If it is the case that practitioners are less aware of the benefits of public goods to agricultural production this would likely reduce the uptake of governance mechanisms, given that no personal benefit would be perceived. Future study of the benefits of public goods to agricultural production, and management to communicate and harness these, may therefore serve to improve uptake of management of public goods.

We combined academic and practitioner maps into a single model using mean link values. Combining maps is common practice (Özesmi & Özesmi, 2003, 2004; Vanwindekens et al., 2013).; however, combined maps also run the risk of diluting links, creating a model which does not represent any stakeholder accurately (Fairweather & Hunt, 2011). Across our maps we identified a single area where stakeholder perceptions disagreed. Within the water quality map academics predicted a negative relationship between green agriculture and agricultural yield, while practitioners predicted a positive relationship. When modelling outcomes this link was of little consequence, as yield did not link back to public goods, directly or indirectly. However, understanding the reasons behind opposing views between stakeholder groups is important for the success of changes in governance mechanisms, and identifying such opposing links is a benefit of FCM making links visible. While it appears that practitioners have a more positive view of the impacts of green agriculture on agricultural yield than academics, we did not define specific actions of 'green agriculture'. It would be expected that practitioners do not consider mechanisms which would reduce yield to be worth considering, while academics may perceive that reductions in yield are acceptable for improvements to public goods. Because we cannot unpack the reasons for drawing the links in this way further exploration of the relationship to green agriculture would be valuable. This also highlights a weakness in our approach through not providing a definition for green agriculture.

Although no opposing links were found within the biodiversity map, the scores for farm viability showed large variation, being highest in the academic model. This may reflect higher optimism in the academic model for farm adaptation, which is not recognised by the practitioners. Because our models identify only perceived relationships we cannot identify which perception is more 'correct', however regardless of actual outcome practitioners will not, and would not be expected to, support governance mechanisms which they perceive will negatively impact farm viability. The link between governance mechanisms and farm viability is therefore one which would benefit from further empirical study, to ensure that farm viability is not unduly impacted, and any impacts can be appropriately compensated.

4.2 Scenarios

Overall our models predicted little change in water quality or biodiversity through alternative governance scenarios. Though the models predict only small changes to biodiversity and water quality it is important to recognise that these are relative values. These values are therefore useful for policy development in identifying where the largest comparative changes may be made, but cannot be used to estimate the absolute magnitude of change, rather forecast the likely dynamics. In our models the largest changes were predicted for technological change, such as precision farming. In recent years precision farming has been recognised as a potential mechanism to increase yield and farm sustainability, and is supported through pillar two of the

CAP (Lind & Pedersen, 2017), and has received substantial funding from the UK Government (Agri-Tech Centres, 2018). While this is encouraging for technological development for improving the provision of public goods from agricultural land, this may also highlight a potentially unfounded 'hope' in technology. In our models practitioners perceive that technological change will deliver increased yields alongside improved environmental outcomes. However, this relationship would also reduce pressure on practitioners to take other actions, which may not have the same positive impacts on yield. While the positive relationship between technological change and biodiversity signposts a mechanism to be considered, further work to understand this link, and to relate this to the wider phenomenon of technological optimism, is needed.

Although we can estimate comparative change, overall change is small across all models. This likely reflects the already high level of environmental policy and regulation in Scottish agriculture, as well as the tendency for stakeholders to consider only incremental, rather than radical, changes to governance, policy and management.

4.3 Limitations

As with all models FCM is limited. Models are not able to incorporate non-linearity, a problem identified by the water quality practitioner group, who noted that more restrictive policy would only have a positive relationship to green agriculture until a threshold of costs to the practitioner was reached. Once policy becomes too restrictive uptake would be reduced, and the positive impact on green agriculture would decline, despite the 'greenness' of the policy itself increasing. This inability to code for non-linearity has been identified as a challenge particularly in models which aim to incorporate ecological relationships (Skov & Svenning, 2003). Agent based FCM provides one option for incorporating non-linearity (Lee, Lee, Lee, & Lim, 2013). Though we are not aware of such models being used currently to answer environmental management questions, gains in modelling of such questions would be expected. In a related problem concepts may also be dependent on different time scales. This presents particular challenges to incorporating climate change into models, as each link is presumed to occur within an equal time step. Rule based FCM provides one option to introduce varied time schedules and time lags (Carvalho & Tomé, 2001), transforming weights into time, and addition of time variation through simulation (Doukas & Nikas, 2019).

The restriction to a single link, with no context, was also identified as a limitation by all groups. The context of agri-environmental systems is highly important, and a link that is positive in one situation may be negative in another. Presenting only the average link could therefore lead to policy decisions which do not reflect reality for all practitioners, particularly damaging if changes were made to regulations. Alternative cognitive mapping methods, such as adapted form of systems mapping (Nikas, Doukas, Lieu, & Tinoco, 2017), can provide such contexts, but also increase the complexity of the task and outputs.

As with all models, FCMs are only as good as the data used to create them. Though stakeholder participation is a benefit of these models, relying on stakeholder knowledge has the potential to code incorrect data that do not reflect underlying biophysical realities. Through assigning numbers to indicate the strength of links FCMs may also present false accuracy, as there is limited opportunity to incorporate uncertainty (Gray et al., 2015; Kok, 2009; Özesmi & Özesmi, 2004). Although the basic FCM is subject to the limitations detailed above, extensions to the method must be carefully considered to ensure that additions reflect the system, and do not increase the potential for false accuracy (Jetter & Kok, 2014), particularly for social components, which may not have a definite 'correct' value. While this is a strength of the method to represent multiple understandings across stakeholders, it also presents challenges for combining and representing all understandings, and it may not be possible to identify a single 'true' model. In order to ensure that the models created are relevant to the question at hand users must therefore pay close attention to selection of representative and knowledgeable stakeholders and the process of participatory modelling, including knowledges of the biophysical systems as well as the social systems, and incorporating qualitative data to account for nuances and uncertainties not captured in the quantitative modelling. This includes the discussions and reasonings brought to play in the participatory modelling process. Although FCM provides a method to code vital, and often excluded, understandings of complex systems it remains most useful when used alongside empirical models. When FCM provides an alternative, rather than an expanded, view of the current understanding it may better contribute to identifying avenues for further empirical study, or areas where dialogue between stakeholders needs to be increased.

4.4 Future Work

Our models predict only small changes to water quality and biodiversity as a result of governance or policy changes, possibly because stakeholders are only able to imagine changes to policy or governance that they themselves have experienced. A wider understanding of revolutionary changes to agricultural policy or governance, which may result in larger changes to biodiversity and water quality, may therefore require more in depth and exploratory participatory methods.

Because FCM is participatory it does not intend to create a single 'objective' model, but seeks to code stakeholder knowledges. This increases the potential for incorrect data to be coded. In the case of the Ugie river catchment it would be beneficial to extend the models of public good provision for agriculture to include existing ecological and biophysical data which characterise the relationships between land use and biodiversity or water quality. Linking this model to spatial variation would further extend the applicability of the model to land management, although would be computationally expensive. Incorporating FCM as a starting point to conceptualise problems and solutions would be a valuable avenue to explore where biophysical modelling is expected to have a real-world policy implication.

5 Conclusions

Policy and governance mechanisms to improve provisions of public goods must act within complex agri-environmental systems. The interlinked socio-ecological concerns, as well as high context specificity, means that decisions must often be taken with imperfect information. We applied FCM in the Ugie river catchment in Aberdeenshire as one method to capture stakeholder knowledges. We found that academics and practitioners provided different, but complementary, understandings of the provision of public goods from agriculture, although models did not predict large changes to either provision of biodiversity or water quality with changes to policy or governance. FCM was an effective method for formalising the mental models of both academics and practitioners, but had limitations in that the scenarios considered were fairly normative, and thus other methods may be better suited to identifying consequences of radical policy or governance change. FCM may therefore be a useful tool for policy makers and planners to increase understanding of the potential wider consequences of policy or management changes, encouraging design of mechanisms which will limit negative side-effects, or prompting measures to be put in place to compensate those negatively impacted. The accessible nature of FCM makes it a valuable tool to facilitate transdisciplinary involvement in co-design of governance mechanisms, while its flexibility enables accommodation of multiple stakeholder interest. The participatory nature of FCM in not only providing data, but also allowing participants to engage with and interpret the results increases stakeholder by in and therefore the legitimacy of imposed change. While stakeholder participation through FCM allows the integration of different stakeholder knowledges, beliefs and perceptions, and enables a deliberative process through model creation, limitations have been identified by stakeholders, including the inability to code non-linear relationships, threshold effects, or time. Thus, the combination of FCM with ecological, biophysical data and cost-benefit analysis could enrich policy designs by integrating a mix of approaches and knowledges.

6 Acknowledgements

We would like to thank C. Barlagne and five anonymous reviewers for their assistance in reviewing and improving this manuscript.

7 Funding details

This work was supported by the European Union's Horizon 2020 research and innovation programme under grant agreement number 633838. Supporting capacity for final completion of the manuscript was provided through The Rural & Environment Science & Analytical Services Division of the Scottish Government.

8 References

Aberdeenshire Council. (2017). *Agriculture Statistics for Aberdeenshire*.

Agri-Tech Centres. (2018). The Agri-Tech Centres of Agricultural Innovation. Retrieved January 14, 2020, from https://www.agritechcentres.com/

Allen, K. E., Quinn, C. E., English, C., & Quinn, J. E. (2018). Relational values in agroecosystem governance. *Current Opinion in Environmental Sustainability*, *35*, 108–115. https://doi.org/10.1016/j.cosust.2018.10.026

Anggraeni, M., Gupta, J., & Verrest, H. J. L. . (2019). Cost and value of stakeholders participation : A systematic literature review. *Environmental Science and Policy*, *101*(October 2018), 364–373. https://doi.org/10.1016/j.envsci.2019.07.012

Baird, J., Plummer, R., Schultz, L., Armitage, D., Bodin, Ö., & Baird, J. (2019). How Does

Socio-institutional Diversity Affect Collaborative Governance of Social – Ecological Systems in Practice ? *Environmental Management*, 200–214. https://doi.org/10.1007/s00267-018-1123-5

Bosma, C., Glenk, K., & Novo, P. (2017). How do individuals and groups perceive wetland functioning? Fuzzy cognitive mapping of wetland perceptions in Uganda. *Land Use Policy*, *60*, 181–196. https://doi.org/10.1016/j.landusepol.2016.10.010

Bremer, L. L., Brauman, K. A., Nelson, S., Prado, K. M., Wilburn, E., & Fiorini, A. C. O. (2018). Relational values in evaluations of upstream social outcomes of watershed Payment for Ecosystem Services: a review. *Current Opinion in Environmental Sustainability*, *35*(November), 116–123. https://doi.org/10.1016/j.cosust.2018.10.024

Byg, A., Novo, P., Faccioli, M., & Kyle, C. (2017). *Public good valuation and governance – PROVIDE workshop report*. Aberdeen.

Carvalho, J. P., & Tomé, J. A. B. (2001). Rule Based Fuzzy Cognitive Maps - Expressing Time in Qualitative System Dynamics. In *10th IEEE International Conference on Fuzzy Systems*.

Christen, B., Kjeldsen, C., Dalgaard, T., & Martin-Ortega, J. (2015). Can fuzzy cognitive mapping help in agricultural policy design and communication? *Land Use Policy*, *45*, 64–75. https://doi.org/10.1016/j.landusepol.2015.01.001

Cooper, T., Hart, K., & Baldock, D. (2009). *The Provision of Public Goods Through Agriculture in the European Union*. Institute for European Environmental Policy: London.

Creaney, R., Novo, P., Byg, A., & Faccioli, M. (2017). *Public good hotspots, governance and information needs from agriculture and forestry in Aberdeenshire: a workshop report.*

Department for Environment Food and Rural Affairs. (2018). *Health and Harmony : the future for food , farming and the environment in a Green Brexit Summary of responses*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741461/future-farming-consult-sum-resp.pdf

Doukas, H., & Nikas, A. (2019). Decision support models in climate policy. *European Journal of Operational Research*, (xxxx). https://doi.org/10.1016/j.ejor.2019.01.017

Duckett, D., Feliciano, D., Martin-Ortega, J., & Munoz-Rojas, J. (2016). Tackling wicked environmental problems: The discourse and its influence on praxis in Scotland. *Landscape and Urban Planning*, *154*, 44–56.

European Commision. (2018). *EU Budget: the Common Agricultural Policy after 2020*. Retrieved from https://ec.europa.eu/commission/news/eu-budget-common-agricultural-policy-after-2020-2018-jun-01_en

Fairweather, J. R., & Hunt, L. M. (2011). Can farmers map their farm system? Causal mapping and the sustainability of sheep/beef farms in New Zealand. *Agriculture and Human Values*, *28*(1), 55–66. https://doi.org/10.1007/s10460-009-9252-3

Gray, S., & Cox, L. (2013). MENTAL MODELER: A tool for environmental planning and research. Retrieved from http://www.mentalmodeler.org/articles/Mental Modeler Manual for Workshop.pdf

Gray, S., Gray, S., de Kok, J. L., Helfgott, A. E. R., O'Dwyer, B., Jordan, R., & Nyaki, A. (2015). Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems. *Ecology and Society*, *20*(2). https://doi.org/10.5751/ES-07396-200211

Hunter, D., Guarino, L., Spillane, C., & McKeown, P. (2017). *Handbook of Agriculutral Biodiversity*. Routledge.

Jetter, A. J., & Kok, K. (2014). Fuzzy Cognitive Maps for futures studies — A methodological assessment of concepts and methods. *Futures*, *61*, 45–57. https://doi.org/10.1016/j.futures.2014.05.002

Kok, K. (2009). The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development, with an example from Brazil. *Global Environmental Change*, *19*(1), 122–133. https://doi.org/10.1016/j.gloenvcha.2008.08.003

Lee, K., Lee, H., Lee, N., & Lim, J. (2013). An Agent-Based Fuzzy Cognitive Map Approach to the Strategic Marketing Planning for Industrial Firms. *Industrial Marketing Management*, *42*(4), 552–563.

Lind, K., & Pedersen, S. (2017). Chapter 12. Perspectives of Precision Agriculture in a Broader Policy Context. In S. Pederson & K. Lind (Eds.), *Precision Agriculture: Technology and Economic Perspectives, Progress in Precision Agriculture*. Springer International Publishing.

Millenium Ecosystem Assessment. (2005). *Ecosystems and Human Well-Being: Biodiversity Synthesis*. Washington, DC. https://doi.org/10.1057/9780230625600

Morris, J., Mills, J., & Crawford, I. M. (2000). Promoting farmer uptake of agri-environment schemes: The Countryside Stewardship Arable Options Scheme. *Land Use Policy*, *17*(3), 241–254. https://doi.org/10.1016/S0264-8377(00)00021-1

Nikas, A., Doukas, H., Lieu, J., & Tinoco, R. A. (2017). Managing stakeholder knowledge for the evaluation of innovation systems in the face of climate change. https://doi.org/10.1108/JKM-01-2017-0006

Özesmi, U., & Özesmi, S. (2003). A participatory approach to ecosystem conservation: Fuzzy cognitive maps and stakeholder group analysis in Uluabat Lake, Turkey. *Environmental Management*, *31*(4), 518–531. https://doi.org/10.1007/s00267-002-2841-1

Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people’s knowledge: A multi-step fuzzy cognitive mapping approach. *Ecological Modelling*, *176*(1–2), 43–64. https://doi.org/10.1016/j.ecolmodel.2003.10.027

Papageorgiou, E., & Kontogianni, A. (2012). Using Fuzzy Cognitive Mapping in

Environmental Decision Making and Management : A Methodological Primer and an Application. *International Perspectives on Global Environmental Change*, 427–450. https://doi.org/10.5772/29375

Potschin, M., Haines-Young, R., Fish, R., & Turner, R. (2016). *Handbook of Ecosystem Services*. Routledge.

Reed, M. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation*, *141*, 2417–2431.

SEPA. (2015). Priority catchments. Retrieved August 22, 2018, from https://www.sepa.org.uk/environment/water/river-basin-management-planning/actions-to-deliver-rbmp/priority-catchments/

Skov, F., & Svenning, J. C. (2003). Predicting plant species richness in a managed forest. *Forest Ecology and Management*, *180*(1–3), 583–593. https://doi.org/10.1016/S0378-1127(02)00646-1

Swinton, S. M., Lupi, F., Robertson, G. P., & Hamilton, S. K. (2007). Ecosystem services and agriculture : Cultivating agricultural ecosystems for diverse benefits. *Ecological Economics*, *64*, 245–252. https://doi.org/10.1016/j.ecolecon.2007.09.020

Takacs, D. (2019). Whose voices count in biodiversity conservation? Ecological democracy in biodiversity offsetting, REDD+, and rewilding. *Journal of Environmental Policy & Planning*, 1–16. https://doi.org/10.1080/1523908X.2019.1661234

Thompson, A. W., Reimer, A., & Prokopy, L. S. (2015). Farmers' views of the environment the influence of competing attitude frames on landscape conservation efforts. *Agriculture and Human Values*, 385–399. https://doi.org/10.1007/s10460-014-9555-x

Turney, S., & Bachhofer, M. (2016). *Package 'FCMapper.'*

Vanwindekens, F. M., Stilmant, D., & Baret, P. V. (2013). Development of a broadened cognitive mapping approach for analysing systems of practices in social – ecological systems. *Ecological Modelling*, *250*, 352–362. https://doi.org/10.1016/j.ecolmodel.2012.11.023

Vliet, M. Van, Kok, K., & Veldkamp, T. (2010). Linking stakeholders and modellers in scenario studies : The use of Fuzzy Cognitive Maps as a communication and learning tool, *42*, 1–14. https://doi.org/10.1016/j.futures.2009.08.005

Voinov, A., & Bousquet, F. (2010). Modelling with stakeholders. *Environmental Modelling and Software*, *25*, 1268–1281.

Westhoek, H. J., Overmars, K. P., & van Zeijts, H. (2013). The provision of public goods by agriculture: Critical questions for effective and efficient policy making. *Environmental Science and Policy*, *32*, 5–13. https://doi.org/10.1016/j.envsci.2012.06.015

Table 1 Environmental outcomes and governance mechanisms presented for creation of FCMs. These were altered by all groups during the mapping process. Based on Byg et al., 2017 and Creaney et al., 2017. Biodiversity and water quality mechanisms were identified independently.

Biodiversity	Good water quality
Governance mechanisms	Governance mechanisms
CAP greening	Green subsidies
Changes in agricultural supply chain	Public pressure
Promote traditional crops	Catchment partnerships
Regulation of agriculture	Regulation of agriculture
Green labelling	Green labelling
Change in narratives on agriculture	Education and extension
Production subsidies	Production subsidies
Green agriculture[1]	Green agriculture
	Taxes on damaging practices
Environmental/Agricultural outcomes	Environmental/Agricultural outcomes
Agricultural yield	Agricultural yield
Good water quality	Biodiversity and habitat
Food security	Food security
Normal water quantity/flow	Water flow/quantity

---

[1] 'Green agriculture' was not strictly defined and included all aspects of agriculture which had an environmental consideration included in some aspect. This included actions which both promoted good environmental outcomes and reduced poor outcomes.

Table 1 *Change in concepts with altered governance scenarios for the combined model. From low (+ (light blue) or – (light orange): less than 1%) to high (+++ (dark blue) or - - - (dark orange):over 5%) change, positive or negative.*

	Biodiversity			Water quality		
	Improved policy	Changed farming	Improved technology	Improved policy	Public and retail pressure	Increased education
Biodiversity	+	+	+++	++	+	+
Water quality	+		+++	++	+	+
Water flow				++	+	+
Habitat	+	+	+			
Broadleaf trees	+++					
Green agriculture	++	+	++	+++	++	++
Traditional crops	+		+			
Mixed farming	+++	+	++			
Yield	+	+	+++			
Farm viability	+++	+++	+++			
Supply chain	+		+++			
Jobs	++	+	- - -			
Food imports	+	-	+			
Food security	+	+	+	+	+	+
Green labelling	+	+++	+			
Technological change				+		+
Pollution	+		+			
Consumer behaviour	+	-	-			
Health priorities				-	+	-
Political pressure				+	- -	-
Public pressure				+		+++
Retail pressure				+		+

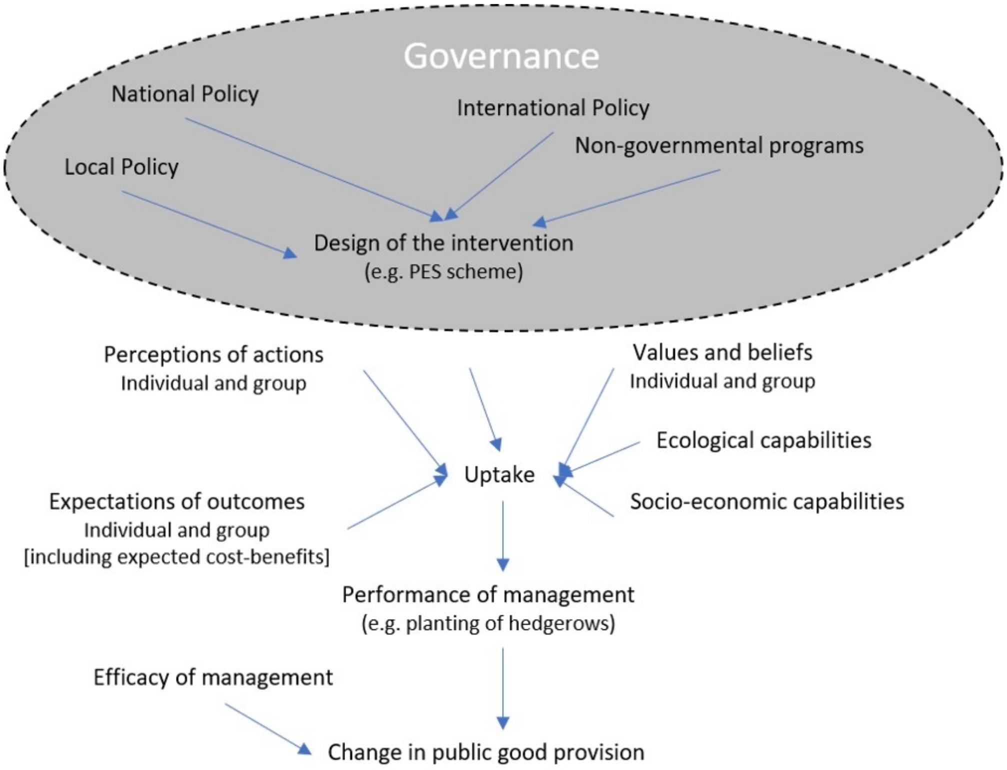


Figure 1 Relationship between governance, policy, intervention and management

157x122mm (149 x 149 DPI)

Figure 2. Map of case study area, Ugie river catchment. Red area indicates Aberdeenshire (Google Maps, 2018)

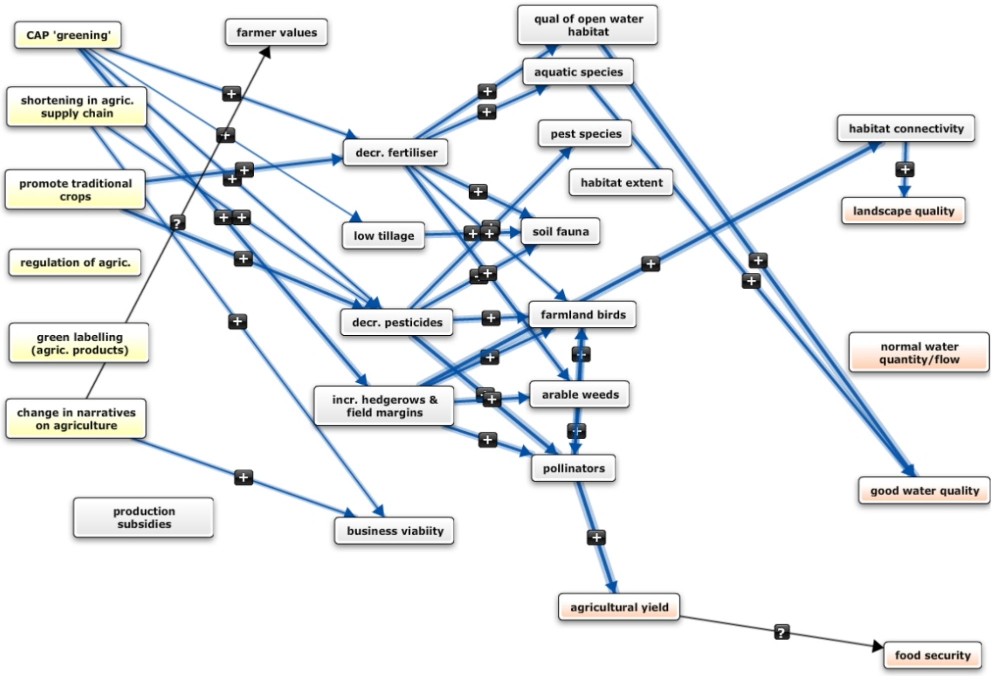


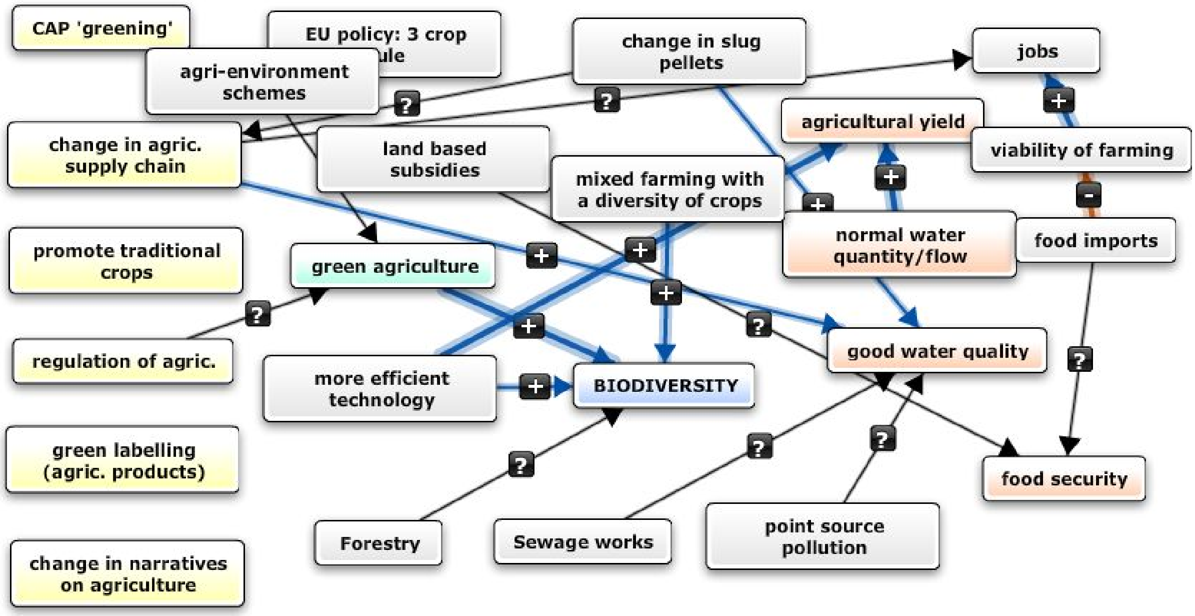
Figure 3 Example FCM: Biodiversity – academics. For others see appendix

Appendix A – Situation of project within PROVIDE H2020 project

This work was situated within the PROVIDE H2020 project (www.provideknowledgeplatform.eu), of which the Ugie river catchment is a case study. The PROVIDE project was concerned with the provision of public goods from agriculture and forestry and was built around four stakeholder workshops. These workshops invited stakeholders to identify important public goods and case studies within their region, support in the design and evaluation of valuation of public goods within the case studies, discuss governance mechanisms for public good provision, and evaluate the potential for transferability of governance mechanisms for the production of public goods. The fuzzy cognitive mapping exercise described in this case study built upon the governance mechanisms recognised a potentially useful by stakeholders to aid understanding of the impacts that these governance mechanisms may have. The results from this work were also combined with data from 12 other European partners to understand similarities and differences across Europe.

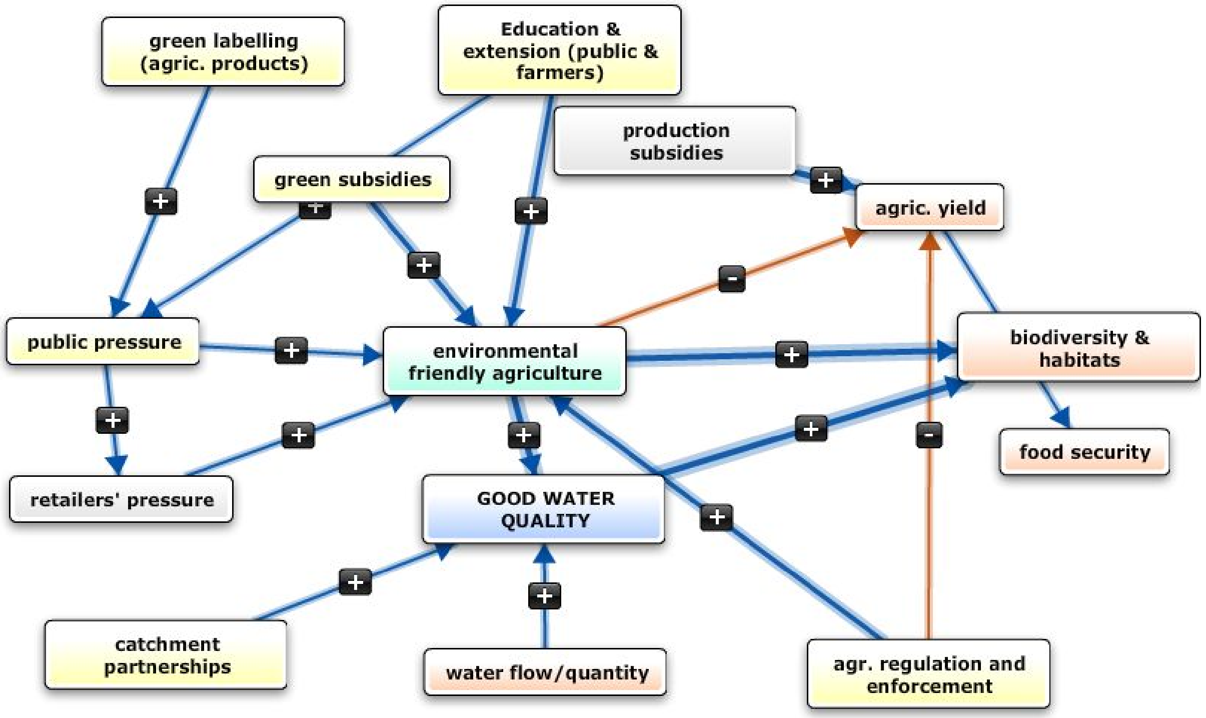
Appendix B – Fuzzy cognitive map for biodiversity created by practitioners

Arrow colours: Blue= Positive relationship, Orange=Negative relationship, Black=Unknown relationship. Line thickness indicates strength of relations (e.g. thicker line= stronger relationship). Box colours: Yellow= Policy or governance indicated by researchers, Orange= Outcomes indicated by researchers, Grey= Concepts added by stakeholders. Green and Blue= Key concepts for consideration when producing the map.



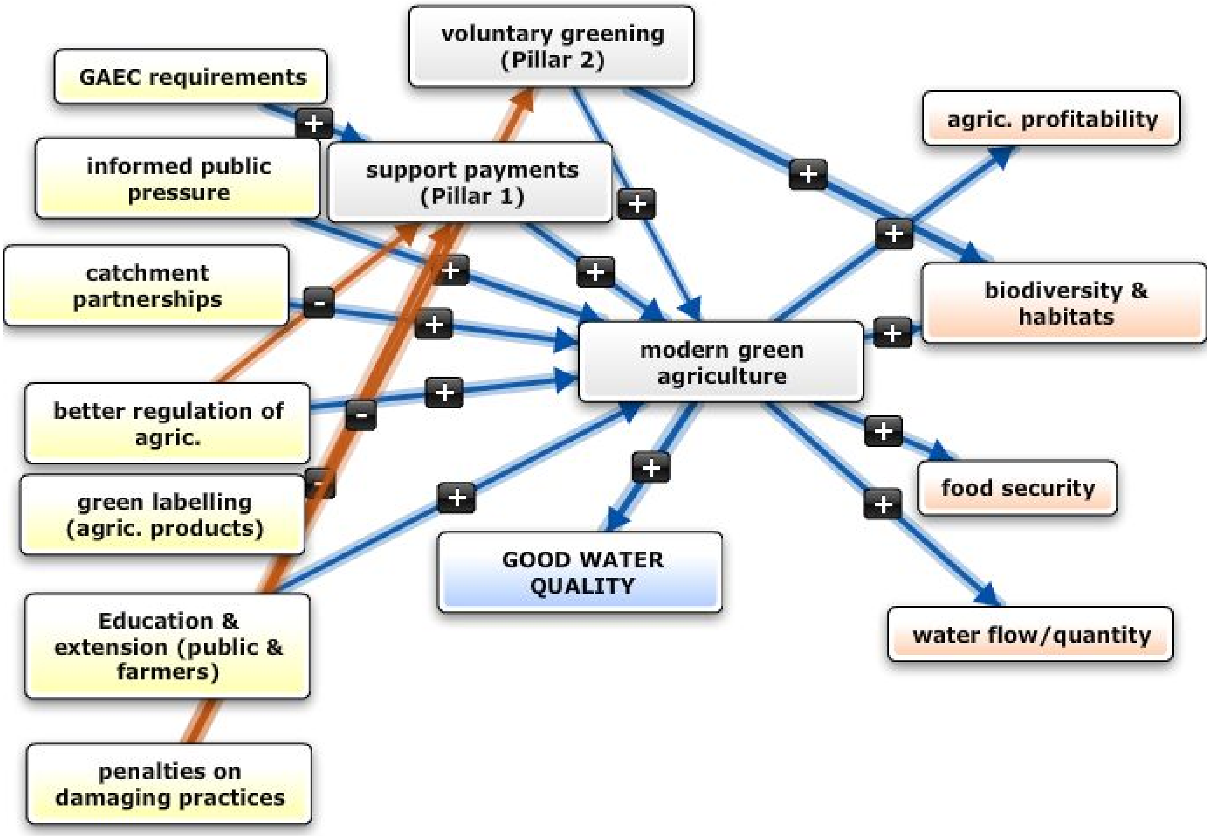
Appendix C - Fuzzy cognitive map for water quality created by academics

Arrow colours: Blue= Positive relationship, Orange=Negative relationship, Black=Unknown relationship. Line thickness indicates strength of relations (e.g. thicker line= stronger relationship). Box colours: Yellow= Policy or governance indicated by researchers, Orange= Outcomes indicated by researchers, Grey= Concepts added by stakeholders. Green and Blue= Key concepts for consideration when producing the map.



Appendix D - Fuzzy cognitive map for water quality created by practitioners

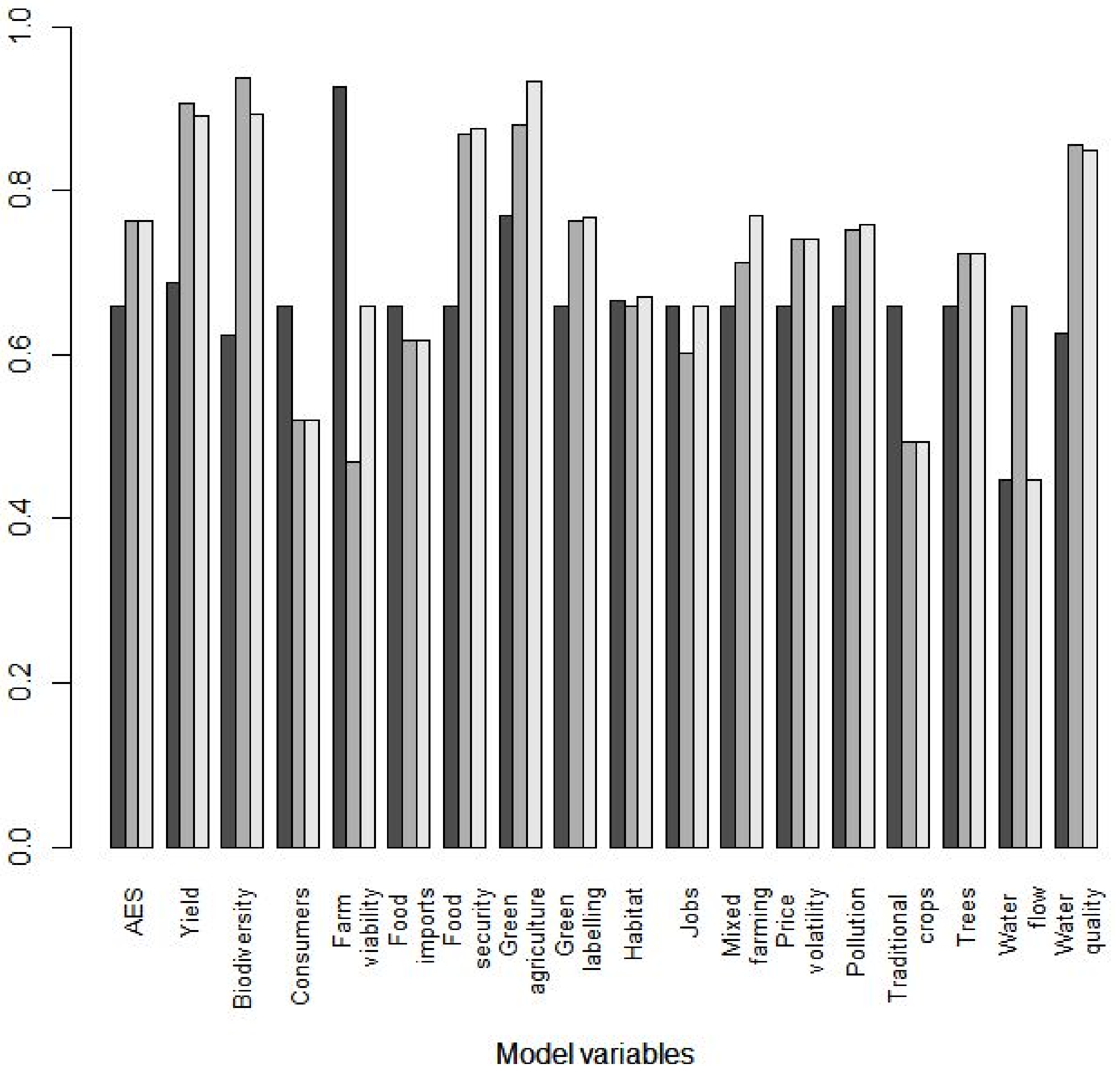
Arrow colours: Blue= Positive relationship, Orange=Negative relationship, Black=Unknown relationship. Line thickness indicates strength of relations (e.g. thicker line= stronger relationship). Box colours: Yellow= Policy or governance indicated by researchers, Orange= Outcomes indicated by researchers, Grey= Concepts added by stakeholders. Green and Blue= Key concepts for consideration when producing the map.



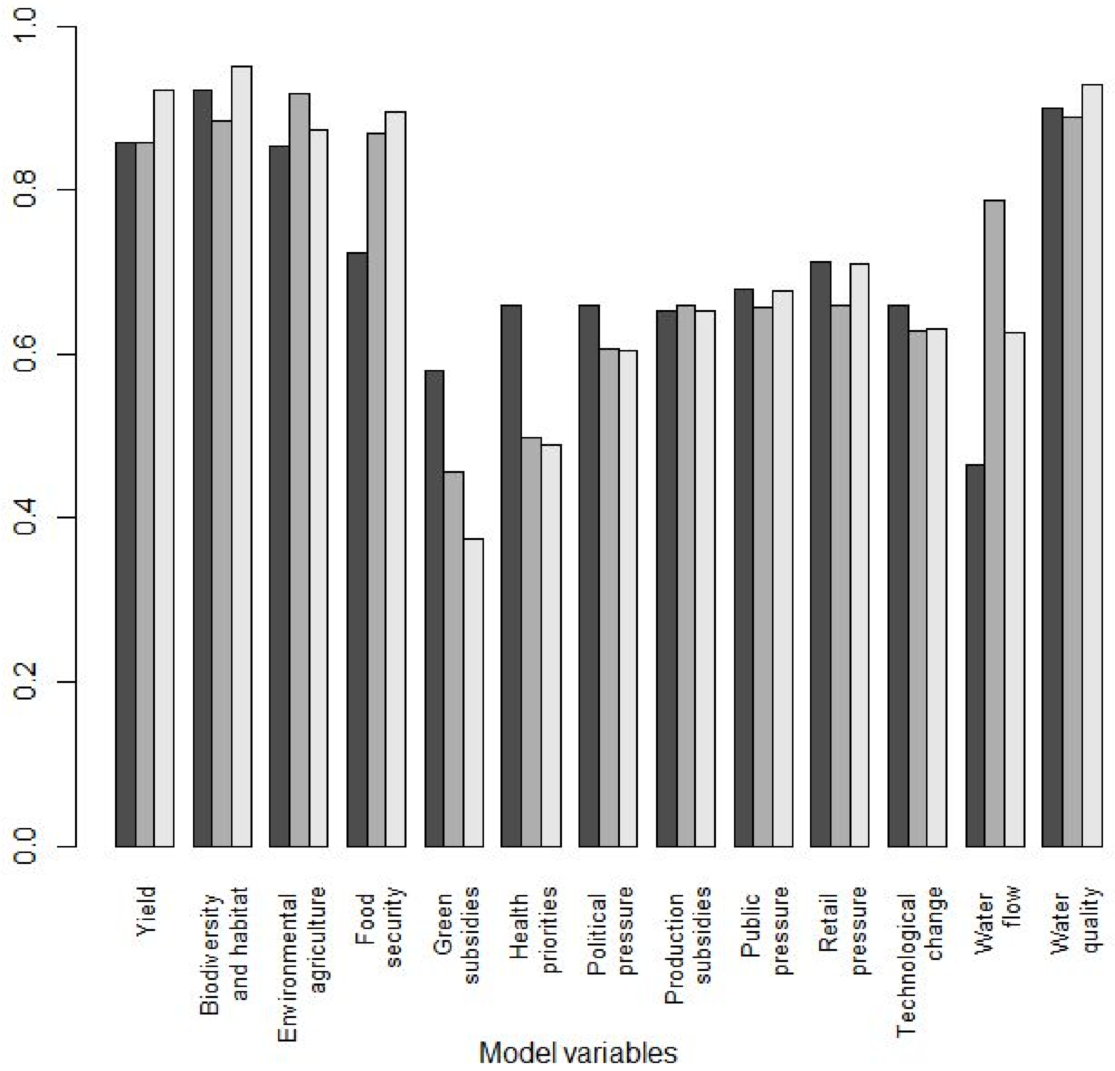
Appendix E - Matrix indices for FCMs produced by academics and practitioners, and combined maps

	Biodiversity			Water		
	Academic	Practitioner	Combined	Academic	Practitioner	Combined
Connections	43	46	64	26	28	43
Connection density	0.05	0.08	0.06	0.08	0.08	0.08
Concepts	30	24	30	18	19	23
Transmitters	7	9	8	8	5	10
Receivers	7	5	3	2	4	2
Connections/ variable	1.4	1.9	2.1	1.4	1.5	1.9

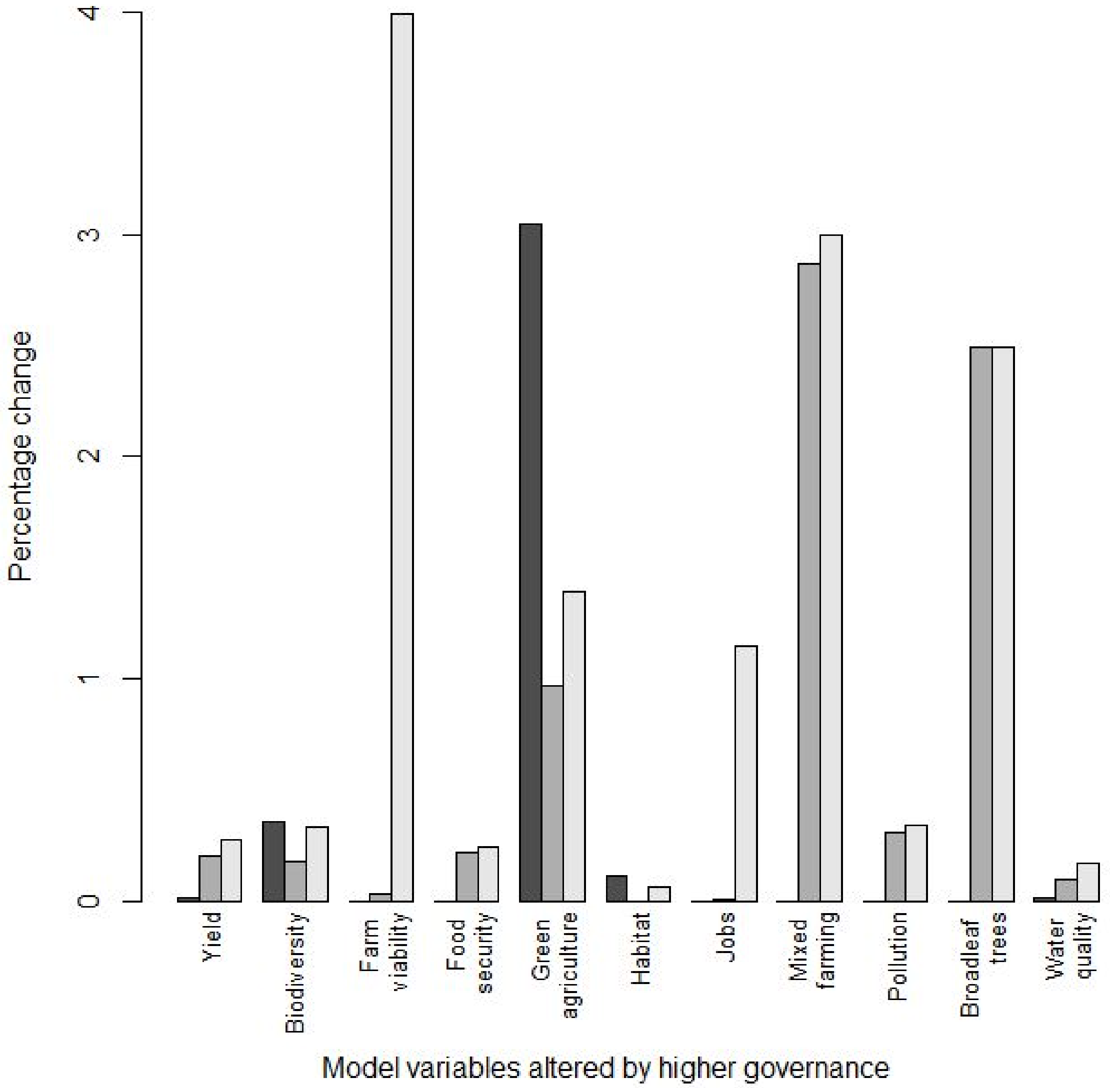
Appendix F – Equilibrium (baseline) values for no changes scenarios for Academic (black), practitioner (dark grey), and combined (light grey) FCM models – biodiversity.



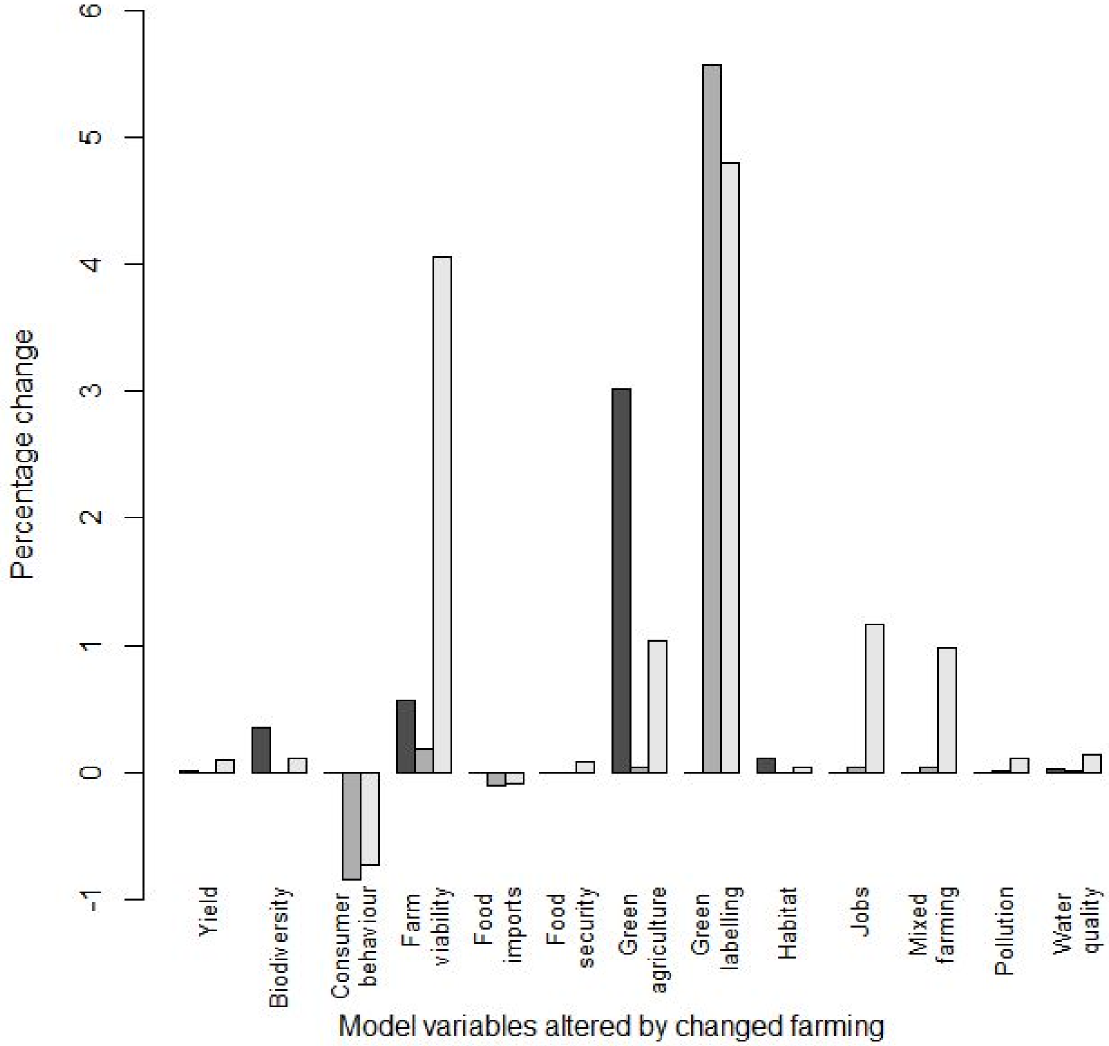
Appendix G - Equilibrium (baseline) values for no changes scenarios for academic (black), practitioner (dark grey), and combined (light grey) FCM models - water quality. 0 link between green agriculture and agricultural yield in combined model



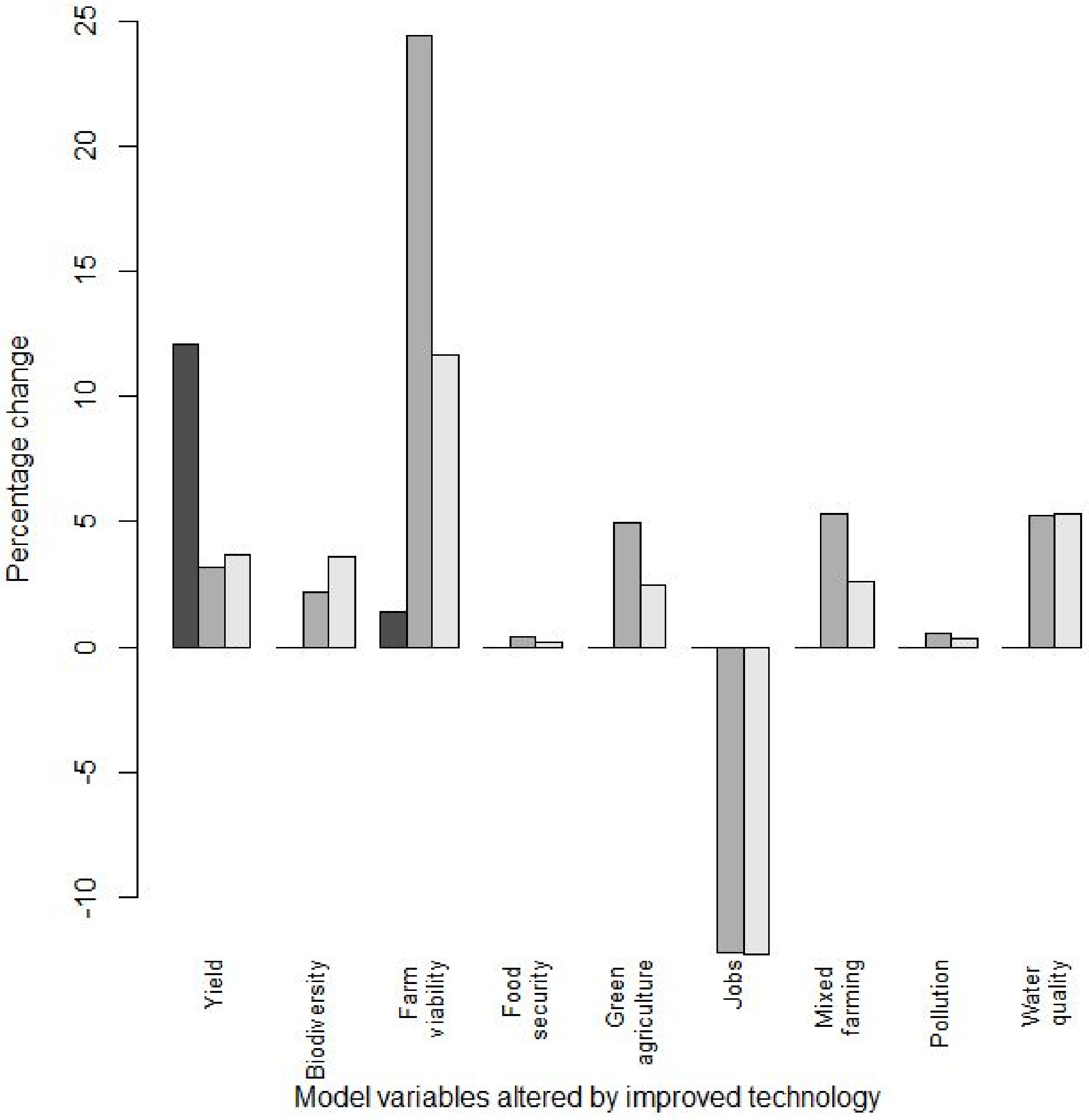
Appendix H Factors impacted by increased governance in Expert (black), Practitioner (dark grey), and combined (light grey) models. Agri-environment Schemes and CAP set to 1.



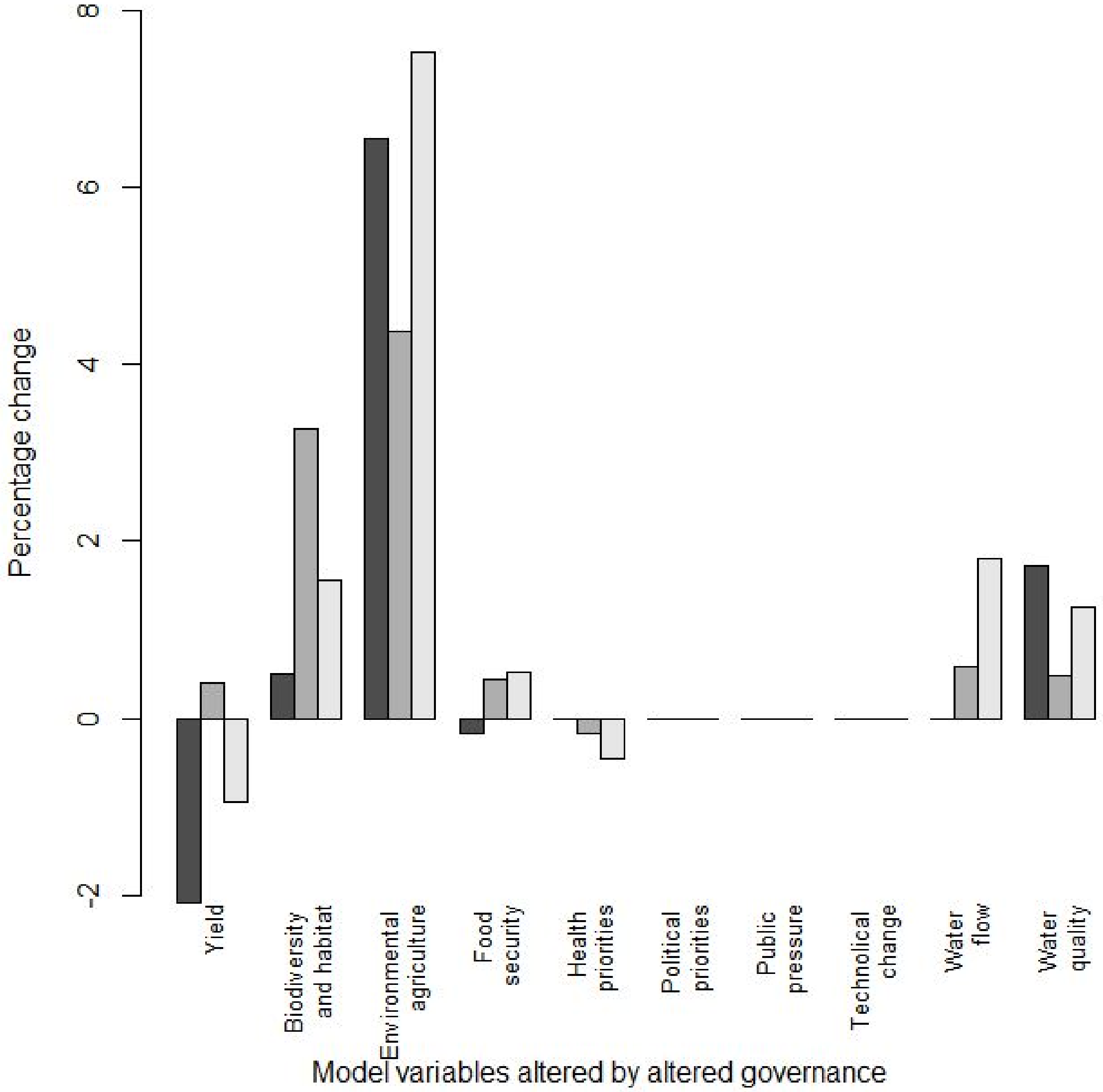
Appendix I Factors impacted by changed farming in Expert (black), Practitioner (dark grey), and combined (light grey) models. Traditional crops and shortened agricultural supply chain set to 1.



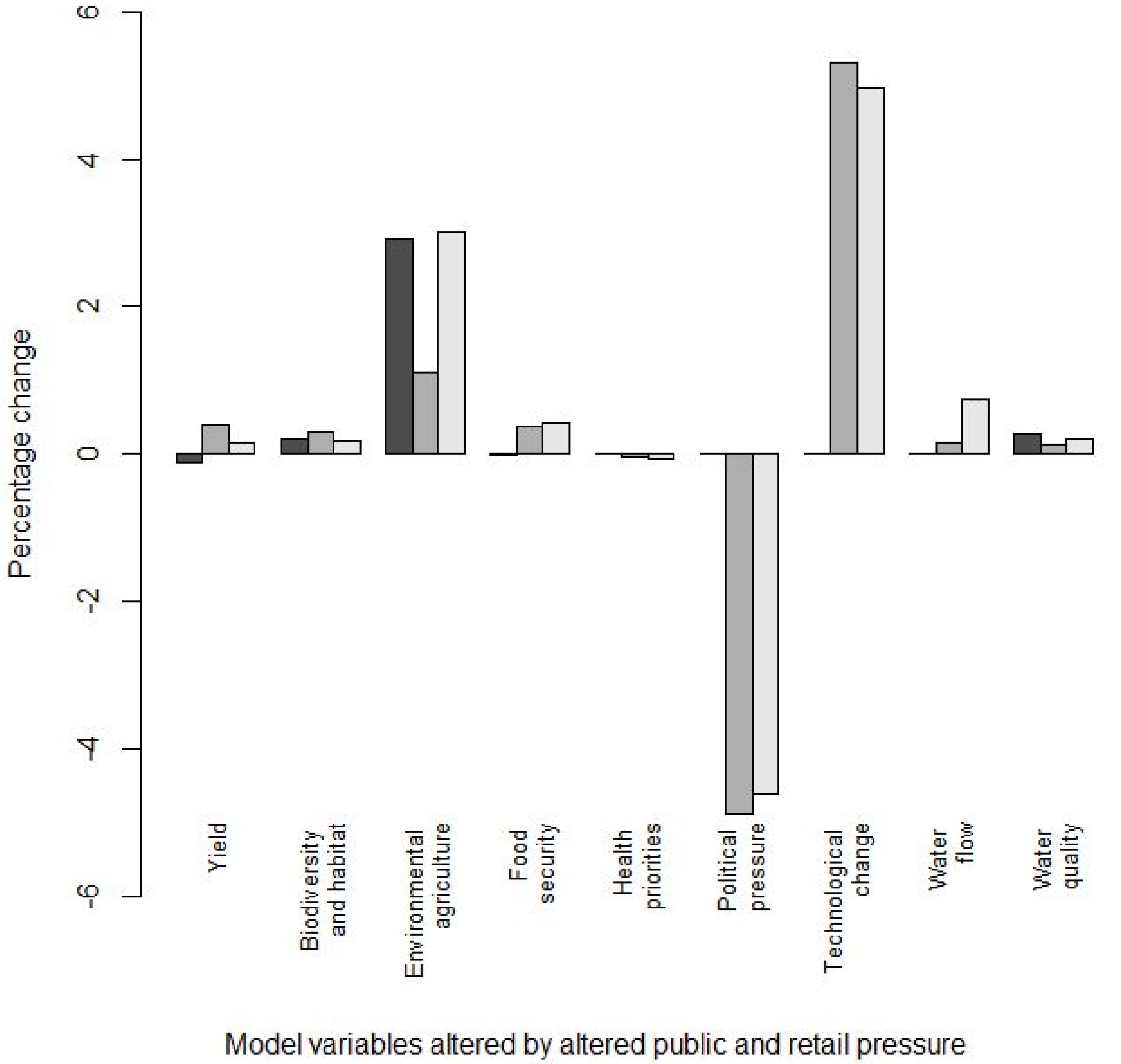
Appendix J Factors impacted by improved technology in Expert (black), Practitioner (dark grey), and combined (light grey) models. Technological breakthroughs set to 1.



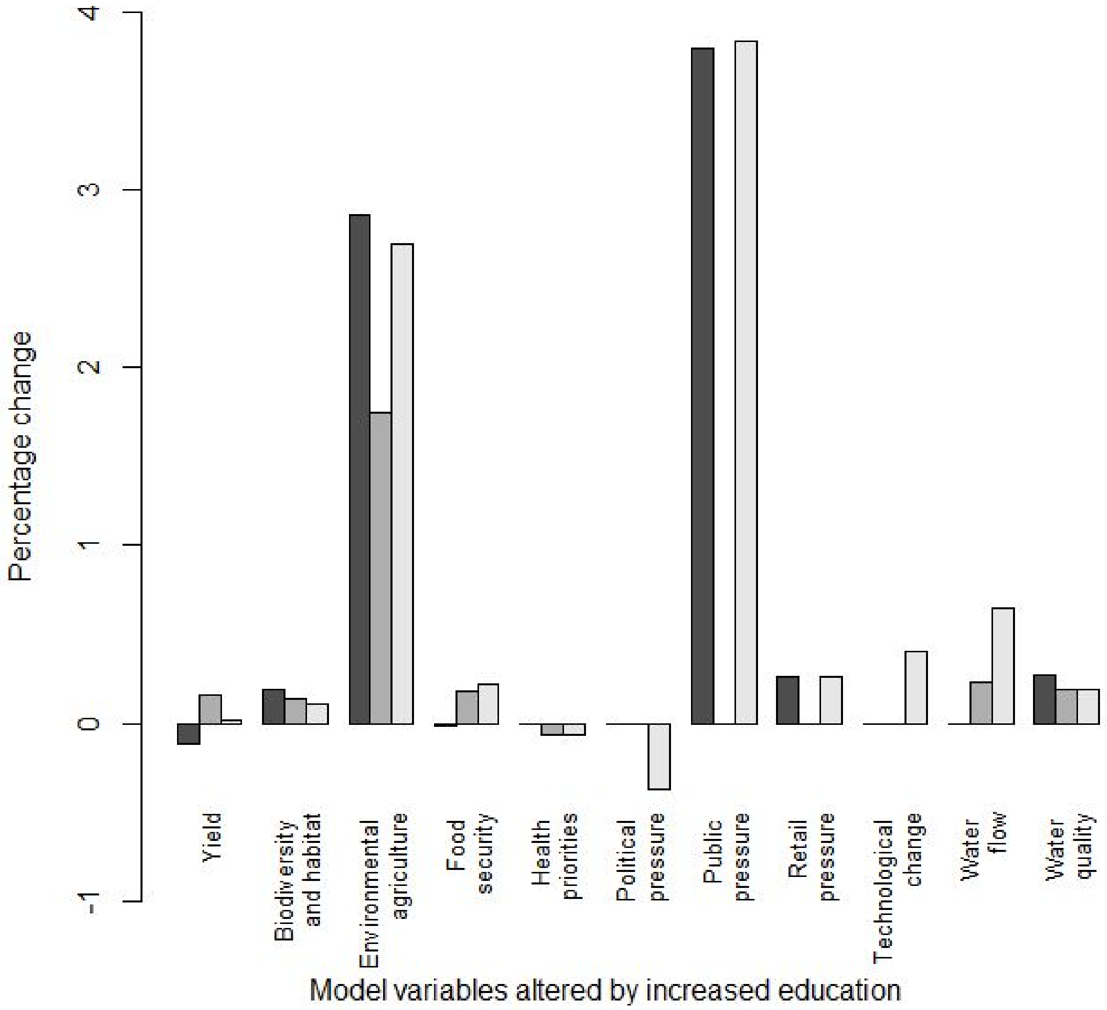
Appendix K Factors impacted by altered governance in Expert (black), Practitioner (dark grey), and combined (light grey) water quality models. Catchment partnerships, agricultural regulations and green subsidies set to 1.



Appendix L Factors impacted by altered public and retail in Expert (black), Practitioner (dark grey), and combined (light grey) water quality models. Public pressure and retail pressure set to 1.



Appendix M Factors impacted by increased education in Expert (black), Practitioner (dark grey), and combined (light grey) water quality models. Education set to 1.


Percentage change
4
3
2
1
0
-1
Yield
Biodiversity and habitat
Environmental agriculture
Food security
Health priorities
Political pressure
Public pressure
Retail pressure
Technological change
Water flow
Water quality
Model variables altered by increased education